# Stimulating innovations from university through the use of digital fabrication – case study of the SciFabLab at Faculty of Mechanical Engineering, University of Belgrade

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Fabrication laboratory (**FabLab**), first created at MIT-USA, is a digital fabrication workshop equipped with tools that enable students to produce their own prototypes and engage in "learning-by-doing" process. Fablab is a do-it-yourself "DIY" workshop with open-source digital design and manufacturing CNC-machines (3D printers, laser cutters and electronics e.g. Arduino, Raspberry Pi), with a strong focus towards technology transfer options and as such is strongly connected with both the small and medium entreprizes (SMEs) and large industry in a unique ecosystem [1]. There are no such ecosystems yet in Serbia. A project started at the University of Belgrade - Faculty of Mechanical Engineering, already possessing fablab-ready infrastructure [CNC (computer-numerical controlled) machines, lab/workshop space and teaching venue] aims to establish one component of such an ecosystem –a Scientific Fab Lab (**SciFabLab**) as a fablab unit dedicated to scientific research using digital fabrication with special focus on possible industrial applications. SciFabLab acts as a connecting hub between scientists, entrepreneurs and SMEs/large industry enabling efficient technology transfer i.e. putting scientific findings to practice by developing unique technology products. The article will present stages of SciFabLab establishment and conclusions about the ensuing stimulation of innovations and modernization of participating faculties, research centers and universities.

**Key words:** innovation, digital fabrication, fabrication laboratory, fab lab

## 1 Fabrication Laboratory - FabLab

A **FabLab** [1, 2], first created at the Massachusetts Institute of Technology (MIT), Boston, USA, is a digital fabrication workshop equipped with tools that allow students to "make almost anything" which is the motto developed by the founder of the Fab Lab concept, Neil Gershenfeld [3,4]. There are over 350 **FabLabs** in 40 countries, open to local inventors, students, scientists, small businesses, and entrepreneurs. FabLab communities are strong in USA, while Europe in general is lagging behind. In Serbia there are currently two fablabs that joined Fab foundation- international FabLab network: Fab Lab Belgrade and Polyhedra Fab Lab, even though both are still in preparatory phases. There is also a first educational FabLab in Serbia being formed as a joint venture of the non-profit organization Fab Initiative run by the authors of this article, Petnica Science Center and Belgrade Metropolitan University, under financial support by the Royal Norwegian Embassy in Belgrade [5].

A case study presented in this article describes the process of establishing a Scientific Fab Lab (**SciFabLab**) as a subunit of the Fab Lab Belgrade. This project is on-going at the University of Belgrade - Faculty of Mechanical Engineering, already possessing FabLab-ready infrastructure [CNC (computer-numerical controlled) machines, lab/workshop space and teaching venue] with the help of the Center of Bioengineering-BioIRC, Kragujevac, Faculty of Engineering, Kragujevac and Faculty of Chemistry, Belgrade.

The main goal of the project is to enable students to use the FabLab equipment for making their own prototypes of the theoretical models from the university courses as well as to provide skills and knowledge to both the students and professors to produce the scale models to be implemented in further STEM education, adaptable for the use both at the high school and university level. Another aim is to establish a facility for manufacturing of the "do-it-yourself" (DYI) instructions for research-grade tools built from low-cost hardware and open-source software. In a nutshell, the main focus is to establish a place where the good ideas can be realized.

## 2 Scientific Fab Lab at the University of Belgrade

The engineering approach from theory to its application, i.e. from an idea to realization is the main idea for establishing Scientific Fab Lab at the University of Belgrade, Faculty of Mechanical Engineering (UB FME). Courses in Hydraulic Machinery, i.e. Hydropower Engineering Teaching Module, incorporates, besides fundamental courses, subjects related to the theory, construction, design and testing of the hydraulic machines (pumps, fans, turbines) and turbocompressors. It is an idea to upgrade this approach to the new level - production of the real and operational models. In this way researchers and students will not only do 3D computer models and simulations, but test real models, after internationally relevant standards. They will be able to realize their ideas and test them.
Software for 3D modelling of axial turbomachines is developed. CAD (computer-aided design) model of one axial fan impeller is presented in Fig. 1a, while real model in Fig. 1b. This 3D model was made by casting and polishing afterwards. Complex geometries are now ready to be produced and tested in quite modern way. New CNC (computer numerical controlled) machines, installed at the UB FME, are presented in Fig. 1c-d.

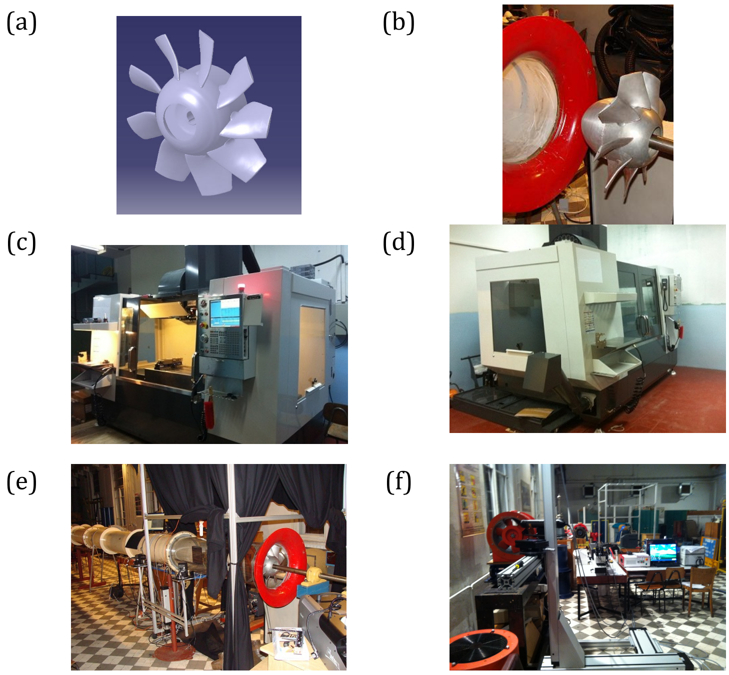


*Figure 1*(a) CAD model of the axial fan impeller; (b) Axial fan impeller. [2] (c-d) CNC machines at the UB FME: (c) 4-axis; (d) 5-axis.e-f) Test rigs with new experimental equipment at the UB FME: (e) Stereo PIV system; (f) LDA system.

Modern CNC machines, like presented in Fig. 1c-d, provide complete highly automated product design using CAD and computer-aided manufacturing (CAM) programs. These CNC machines use G-code, standardized programming language. They have many functions like milling, drilling and turning and operate in various materials from plastic to steel. First one (Fig. 1c) has 4 axis, i.e. X and Y on the horizontal moving table and Z directed through the rotating spindle, while one rotational is added to the table. Five axis machine has two rotational axis (Fig. 1d). Software for machining simulation is very important. Nowadays the whole machine, modelled accurately, allows simulation software to predict fairly accurately tool and part paths, and check if a production cycle would involve a crash. In the case of 5-axis machining this is strongly recommended.
Afterwards, researchers and students on Master and PhD study levels have also chance to complete their machine tests on one of the test rigs. In Fig. 1 are presented modern experimental techniques for flow study in the technical systems where these machines are usually used. Stereo Particle Image Velocimetry (Stereo PIV) (Fig. 1e) and Laser Doppler Anemometry (LDA) (Fig. 1f) are sophisticated systems for turbulent flow study.
Projects for upgrading the existing test rigs for testing pumps, turbines, hydro-equipment, fans, turbocompressors and etc. would encourage not only researchers and students in this field, but also industry. In addition, it is a plan that Scientific Fab Lab would involve other modern production methods, which would help, for example, production of the radial closed turbomachine impellers.

## 3 FabLab scale models in STEM education

Contemporary STEM (science, technology, engineering, math) education is based on the problem-based learning projects approach, with the following objectives [7]: to increase the ability of students for performing enquiry-based tasks; to develop students' self-directed skills; to develop students' ability to work and function in groups; to develop students' research and information retrieval skills; to prepare students for their professional life in the future (engagement with complex problem or scenario, that is sufficiently open-ended to allow a variety of responses or solution, etc.)

Problem based learning in engineering education is typically based on the scale models produced by firms with long time experience and reputation in production of education equipment like: Feedback Instruments Limited; Armfield Limiter; G.U.N.T. Gerätebau GmbH; QuanserColsulting Inc. Typically, laboratory models are high quality products that are expensive, with specializd user interface and limited educational potential. The software tools for use with these products are mainly developed with expensive software packages like Matlab/Simulink or LabVIEW. Users get tutorial for using of already developed software with recommended educational methodology.

On the other side, products like: Fischertechnik; NXT LEGO Mindstorms are less expensive and intended for users of younger age. Besides use for science promotion, they are adequate as sophisticated tools for education of youngsters, and are used in university education also. Main advantages are available prices, modular design, flexibility of applications, and are therefore adequate for mass education (the price of one lab workplace as significant indicator). Generally, on the global market there is a lack of contemporary laboratory systems with open architecture having available prices. However, FabLab concepts can support generation of such products which are modular, customizable with acceptable prices. Moreover, scale models can be products of student education through a contemporary paradigm of STEM problem based learning approach.

Student project implementations should use a new approach for synthesis of laboratory models which are based on the following technological trends: FabLab concept of product development (product digital fabrication); Mechatronics approach for product development (Integration based on synergistic effects of electrotechnical, mechanical and software engineering, i.e. integration of different kind computers in products like on Fig. 2).

More precisely, innovative characteristics of student products should be: Open architecture and product modularity; Possibility for mechanical housing components to be produced digitally by user according to FabLab principle using 3D printers and supplied digital code in data file defining 3D printed form; Acceptable prices and educational potential that is based on products fabrication documentation, set of typical software examples and case studies according to standards defined by "project user".

Digital production has the important benefit that the product can be made locally by the user having the digital code in file defining the shape of the object that can be produced by some method of FabLab fabrication.

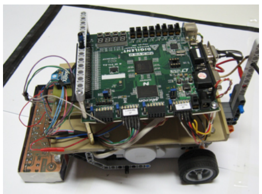

*Figure 2*Illustration of the student project: Integration of Nexys2 FPGA Board in the mobile robot [6]

Planned products and production technology stimulate technological improvements as they directly promote science – STEM and contemporary education which should enable higher level of learning, problem oriented education, using of computer supported technology by students, integral approach to design of devices and systems, understanding of concepts and principles of physical phenomena and systems of engineering.

## 4 DIY scientific equipment produced in the SciFabLab

FabLab equipment in combination with free and open sharing of detailed design blueprints and accessible development tools, allows the research scientists and, especially, educators to customize existing lab equipment or even build sophisticated lab equipment from scratch for a mere fraction of what commercial alternatives cost [11]. The authors collaborate with two laboratories in USA and Canada that possess expertise in manufacturing of the research-grade tools built from low-cost hardware and open-source software (Backyardbrains and Pelling lab, University of Ottawa). Currently, the first prototypes of the 3D printed pipette are being optimized (Fig 3), while the DIY CO2 incubator/bioreactor for mammalian cell culture is in preparation. The produced DIY wet-lab equipment will be tested and utilized in the Center for Bioengineering-BioIRC and at the Faculty of Chemistry, University of Belgrade.

### *4.1 Open Labware designs for a biology/chemistry lab*

The table shows the sources intended for the DIY tools for biology/chemistry labs to be produced in the SciFabLab

*Table 1Open Labware designs, adapted from [11]*

| Area | Project | Source |
|---|---|---|
| Microscopy | Smartphone Microscope | http://www.instructables.com/id/10-Smartphone-to-digital-microscope-conversion |
| | Raspberry Pi Microscope | http://www.thingiverse.com/thing:385308 |
| Molecular Biology/Chemistry | Thermocycler (PCR) | http://openpcr.org/ http://www.thingiverse.com/thing:151406 |
| | Centrifuge | http://www.thingiverse.com/thing:73910 |
| | Colorimeter | http://www.thingiverse.com/thing:255519 |
| Other | Micropipette | http://www.thingiverse.com/thing:210756 |
| | Syringe pump | http://www.instructables.com/id/The-simplest-vacuum-pump-in-the-world/ |
| | Vacuum pump | |

*Figure 3Prototype of a 3D printed micropipette produced in the SciFabLab in cooperation with PolyhedraFabLab*

## 5 Conclusion

The Scientific Fab Lab (**SciFabLab**) is being formed at the University of Belgrade - Faculty of Mechanical Engineering in collaboration with the non-profit organization Fab Initiative, Center for Bioengineering-BioIRC-Kragujevac, Faculty of Engineering -Kragujevac, Faculty of Chemistry at University of Belgrade and in close cooperation with the already existing Fab Labs in Belgrade - Polyhedra Fab Lab and Fab Lab Belgrade. In fact, the SciFabLab is intended to operate as the subunit of the Fab Lab Belgrade, dedicated to scientific research using digital fabrication with special focuson possible industrial applications. Currently, the existing infrastructure is being used for the fabrication of the 3D models for the Courses in Hydraulic Machinery at the FMU, for the first prototypes to be used as the scale models in STEM education, and for DIY research-grade tools. The next steps will be focused on integrating the entrepreneurship aspect and enabling students, professors and scientists to start the technology transfer process. This will require establishing a network with the Business Technology Incubator of the Technical Faculties, the Innovation Fund, Serbian Venture Network and other similar organizations. The initial contacts have been already established and the solidifaction and actual new projects are well on the way.

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